Predictability of Particle Trajectories in the Ocean

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LONG-TERM GOALS

The long term goal of this project is to determine optimal sampling strategies for drifting observing systems, such as buoys and gliders, in order to enhance prediction of particle motion in the ocean, with potential applications to ecological, search and rescue, floating mine problems, and design of real-time observing systems.

OBJECTIVES

Our main objective is to develop Lagrangian techniques to improve our fundamental understanding of turbulent transport phenomena in the ocean. The objectives of the project serve the ONR thrust area of adaptive sampling and Lagrangian tracing. Another aspect of the proposed research focuses on a better understanding of the nature of mesoscale and sub-mesoscale turbulent processes, which is relevant to ONR thrust area on sub-mesoscale variability associated with fronts, turbulence and mixing.

APPROACH

The work is based primarily on the analysis of output from coastal and ocean circulation models, as well as data from drifters and VHF radars deployed for real-time experiments. We also develop and/or employ Lagrangian models and techniques as needed.

WORK COMPLETED

1) Analysis of relative dispersion from synthetic drifter trajectories derived from the Navy Coastal Ocean Model (NCOM) configured in the Adriatic Sea, and publication of a paper (Haza et al., 2008).

2) Analysis of the relative dispersion characteristics as a function of spatial scale using finite-scale Lyapunov exponents (FSLEs) from a wide range of data sources, namely a large-scale ocean model (HYCOM), operational coastal model (NCOM), idealized, buoyancy driven flows using ROM, real drifters released in the Adriatic circulation (in collaboration with P.-M. Poulain), VHF radar data in a sub-mesoscale coastal setting (in collaboration with Anne Molcard from U. Toulon).

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14. ABSTRACT
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3) We are presently (September 17 to mid October, 2008) participating in the REA (Rapid Environmental Assessment) trials organized by NURC/NATO (led by A. Alvarez and M. Rixen) and NRL (led by E. Coelho). Our main role is to compute 3D FSLEs in two nested domains of NCOM in order help guide the three gliders used in the experiment.

RESULTS

Our main effort over the past year has been to explore the FSLE distributions from a variety of numerical simulations and real measurements in the ocean. This investigation is not only attractive from a theoretical perspective, but is also likely to provide further insight in practical applications, such as in REA trials. The study of relative dispersion via the FSLEs is of great interest, because this brings us closer to the following fundamental issues:

(i) The inverse of FSLE is a measure of the predictability time limit. As such, quantification of relative dispersion lies at the very core of applications involving optimization of targeted drifter or glider launches.

(ii) FSLE is a good measure of multi-scale processes, and provides insight into how multi-scale interactions occur in oceanic flows. This can be assessed not only from FSLE maps by visualizing where the small-scale structures are located with respect to the main features, but also from statistical FSLE distributions as a function of spatial scale.

(iii) FSLE naturally highlights turbulent processes at scales smaller than meso-scale, or scale of the largest turbulent coherent structures. The nature of the processes at these scales is not very well understood in the ocean, but play an critical role in all short-term practical applications. Ultimately, this issue reveals itself when ocean modelers advect synthetic drifters with an assumed physical scale of a few meters using velocity fields computed at scales of a few to tens of km.

(iv) Statistical distributions of FSLE as a function of spatial scale from different types of flow fields appears to show only a few characteristic regimes. As such, FSLE can potentially provide a practical and unified metric that quantifies how different flow topologies control the Lagrangian (particle and tracer) spreading.

(v) Finally, Lagrangian particle releases with the objective of quantifying relative dispersion via the FSLEs naturally also measure the degree of randomness or information content in the flow field, as a function of spatial scale. This has direct implications for sampling requirements of the observational systems.

1) Relative dispersion in the open ocean:

Preliminary estimates of the FSLE distribution from HYCOM high-resolution experiments in the Gulf Stream region (Fig. 1a), using on-line or off-line releases are shown in Fig. 1b. This analysis depicts very different regimes; a combination of exponential (sub-meso scale), Richardson (mesoscale) and diffusive (large scale). Also, there is a significant difference between on-line and off-line trajectory calculations at scales smaller than the radius of deformation. Probably the most pronounced feature in this plot is the FSLE plateau at scales smaller than 50 km, namely below the Rossby radius of deformation. As such, chaotic advection induced by the meso-scale eddies and jet (coherent turbulent features) commands the maximum FSLE, or the shortest predictability time (some 1-2 days from Fig. 1b).

2) Relative dispersion in the coastal ocean:

The FSLE distribution as a function of spatial scale from NCOM model, DOLCEVITA and MED drifters (launched by P.-M. Poulain) and DART drifters are shown in Fig. 2. At the first glance, there seems to be an excellent agreement, almost all showing an approximately ballistic regime. We also note that this behavior is different than results from large-scale HYCOM in that there is only one relative dispersion regime. Nevertheless, several details are important. First, most of the data from real drifters are obtained on the basis of chance pairs, which introduce a bias by collecting along the western Adriatic current, thereby favoring shear dispersion (ballistic by definition). Second, FSLE from NCOM flattens at small scales, possibly because of unresolved dynamics, or the emergence of an exponential regime. In fact, when FSLE is estimated from original pairs, instead of chance pairs, the FSLE plateau is recovered.

We conclude that the FSLE plateau at small scales can be missed in the presence of temporal undersampling, and/or spatial sampling biases introduced when relying on chance pairs.

The behavior of a buoyant coastal current is studied using idealized numerical simulations with ROMS in order to develop a better understanding of the dynamics of the WAC. This study also creates the opportunity to explore the relative dispersion when the underlying Eulerian flow is baroclinically unstable. The resolution of the baroclinic instability and subsequent turbulent cascade processes require a large number of grid points. A comparison of snapshots of the surface salinity field from a ROMS simulation with a grid spacing of 4 km and 0.5 km is shown in Fig. 3 (upper panels). The main point in this set of experiments is that the 4-km grid is just adequate to capture the largest eddies resulting from the baroclinic instability (deformation radius is between 10 to 15 km), while with the finer grid, we are able to resolve part of the energy cascade spectrum. A comparison of the relative dispersion via the FSLE (Fig. 3, lower panel) shows that when the model spatial resolution is increased, relative dispersion becomes faster, not only at sub-mesoscales, but also at larger scales as well. This could be either because the forcing, namely the introduction of the buoyant current into the model domain, is somewhat sensitive to resolution, or the small scale turbulence impacts the larger-scale flows via so-called backscatter. We also note that the presence of an FSLE plateau in all cases, with the onset shifting to smaller scales as the model resolution is increased.

These simulations indicate that both the amplitude and scale width of the FSLE plateau appear to be dependent on model resolution, thus possibly to the resolved/simulated Reynolds number of the flow field.

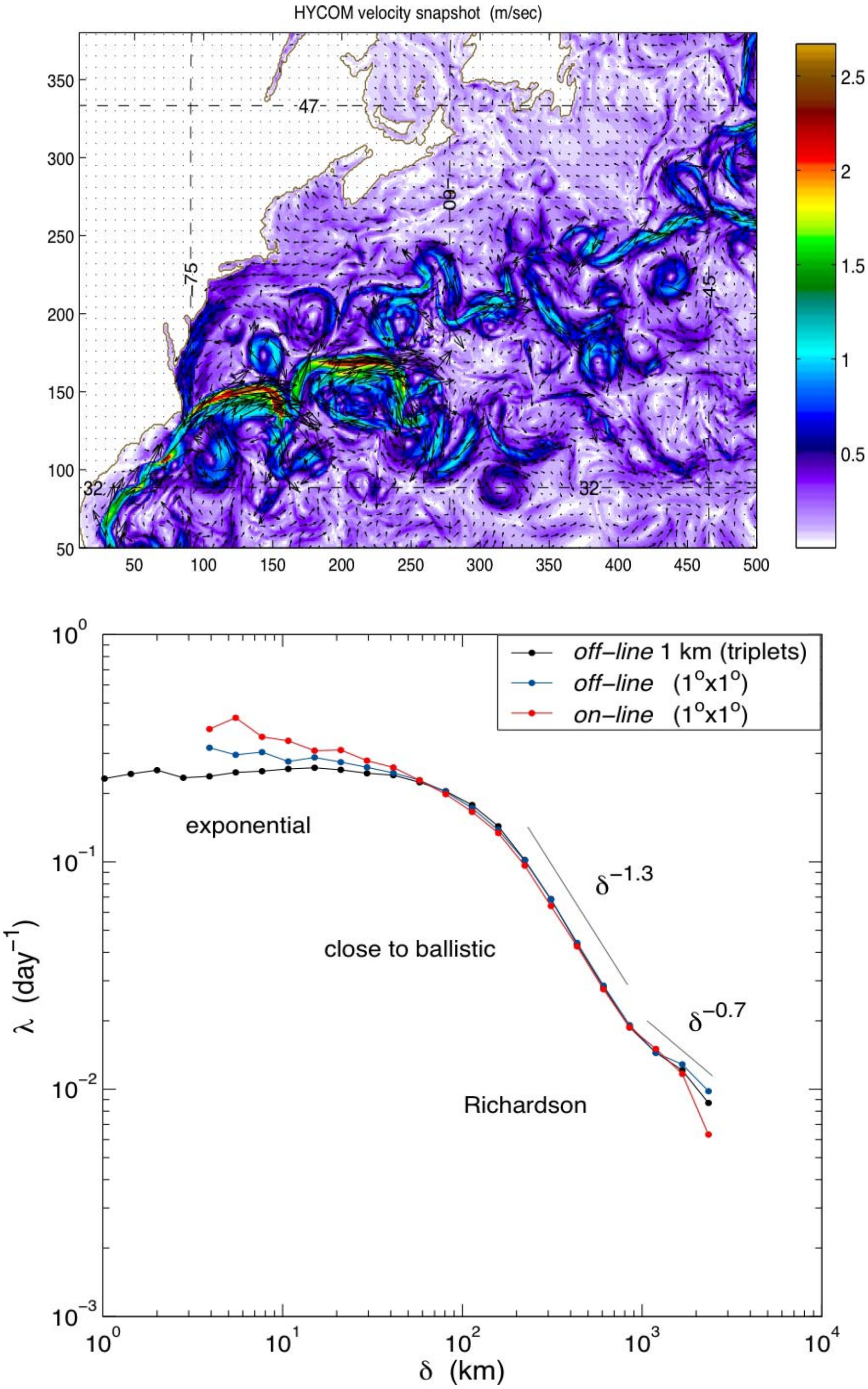

Fig. 1: (Upper panel) Snapshot of the surface velocity field from 1/12 degree HYCOM in the Gulf Stream region. (Lower panel) FSLE of the Gulf Stream surface flow obtained from HYCOM synthetic drifters. The off-line launches (by 1-km triplets in black and on a 1 by 1 degree array in blue) show how the launch sampling and subsequent chance-pair formation affect the dispersion at scales below the radius of deformation, while the on-line (in red) /off-line identical launches show the effect of low-pass filtering of the flow on relative dispersion at those same scales.

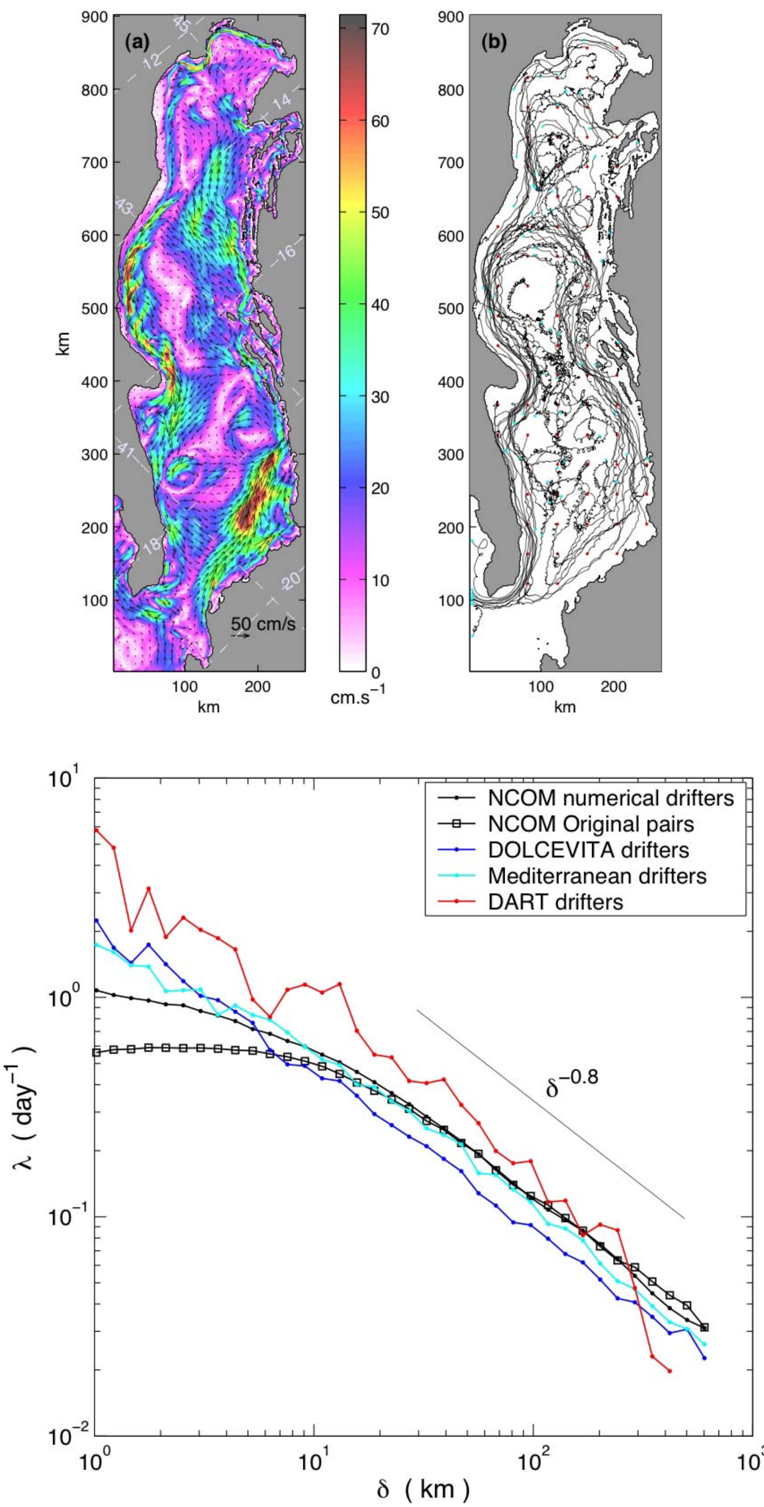

Fig. 2: (Upper panels) Circulation features as measured by the Eulerian field and Lagrangian drifters from NCOM. (Lower panel) FSLE of the Adriatic surface circulation computed from three drifter data sets (Mediterranean, DOLCEVITA and DART), superimposed on the FSLE obtained from synthetic drifters in NCOM. Note the emergence of an FSLE plateau when high-resolution original drifters are used, which indicates a measurement bias by sampling with chance pairs.

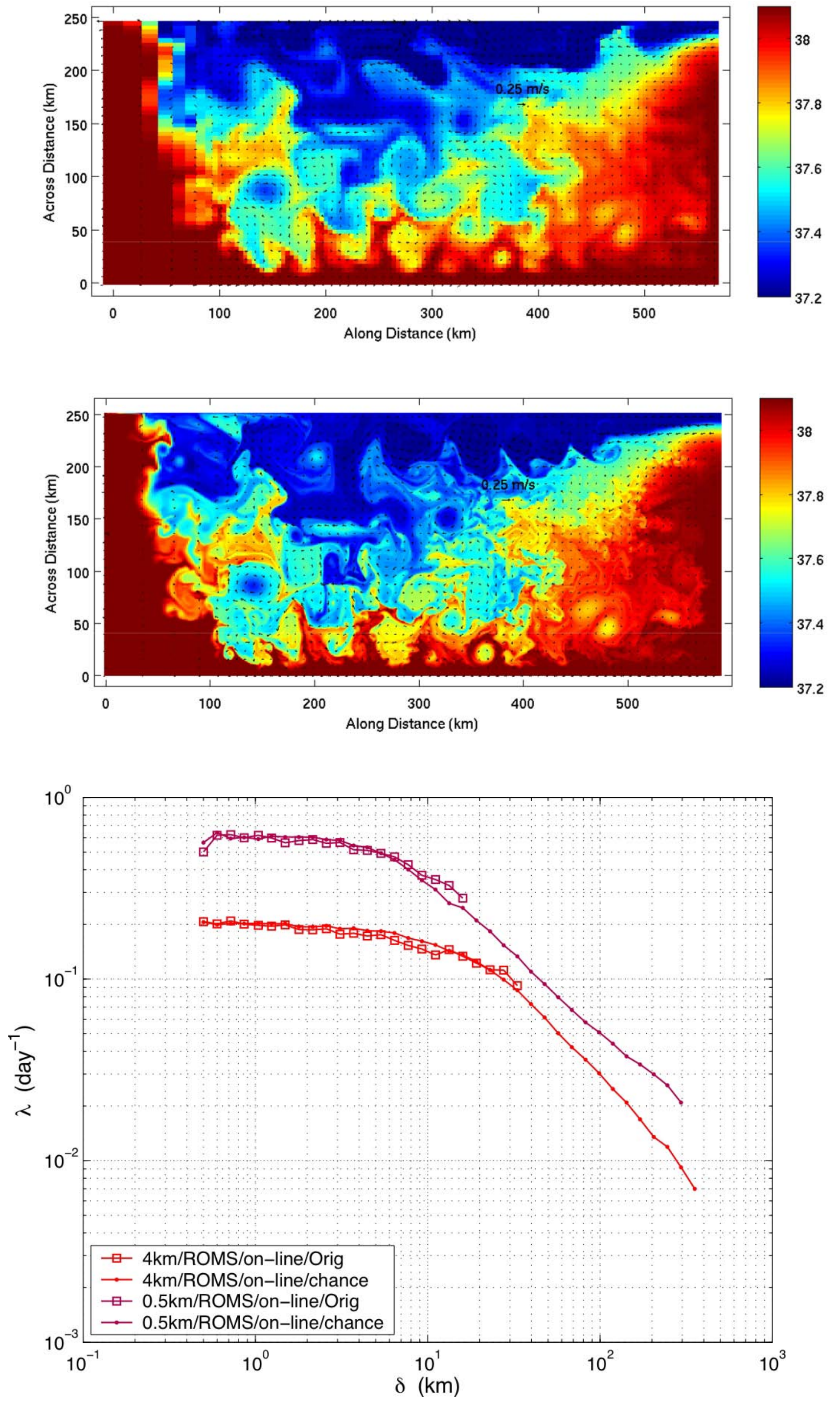

Fig. 3: (Upper two panels) Salinity distribution from simulations of a baroclinically-unstable coastal buoyant current with ROMS at 4-km and 0.5-km grid. (Lower panel) FSLE distributions based on sythetic drifters from 4-km and 0.5-km experiments.

(3) Studies on DART06 and LASIE07 data sets:

We are working on two studies, mainly in collaboration with Anne Molcard, who has visited RSMAS under the support ONR-EU. The first study revolves around improving the prediction of particle trajectories using the Lagrangian sub-grid scale model developed by Haza et al. (2007a) with application to NCOM using the drifter data set collected under the DART06 (Dynamics of the Adriatic Sea in Real Time). The second study is on the analysis of FSLEs from VHF radar data collected during the LESIE (Ligurian Air Sea Interaction Experiment) in 2007.

IMPACT/APPLICATIONS

The investigation of the predictability of particle motion is an important area of study, with a number of potential practical applications at very different scales, including searching for persons or valuable objects lost at sea, tracking floating mines, ecological problems such as the spreading of pollutants or fish larvae, design of observing systems and navigation algorithms.

RELATED PROJECTS

Lagrangian Turbulence and Transport in Semi-Enclosed Basins and Coastal Regions, PI: A. Griffa, N00014-05-1-0094.

Statistical and Stochastic Problems in Ocean Modeling and Prediction, PI: L. Piterbarg, N00014-99-1-0042.

Optimal Deployment of Drifting Acoustic Sensors: Sensitivity of Lagrangian Boundaries to Model Uncertainty, PI: A. Poje, N00014-04-1-0192.

PUBLICATIONS (2007-2008)

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Haza, A., A.C. Poje, T.M. Özgökmen, P. Martin, 2007: Relative dispersion from a high resolution coastal model of the Adriatic Sea. Presented by A. Haza in REA conference.

Haza, A., A.C. Poje, T.M. Özgökmen, P. Martin, and Z.D. Garraffo, 2008: Relative dispersion from a high-resolution coastal and ocean models. Presented by A. Haza in *Ocean Sciences Meeting* in March 2008, Orlando.